Combining sea state and land subsidence rates in an assessment of flooding hazards at the Danish North Sea coast

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Combining sea state and land subsidence rates

in an assessment of flooding hazards at the Danish North Sea coast

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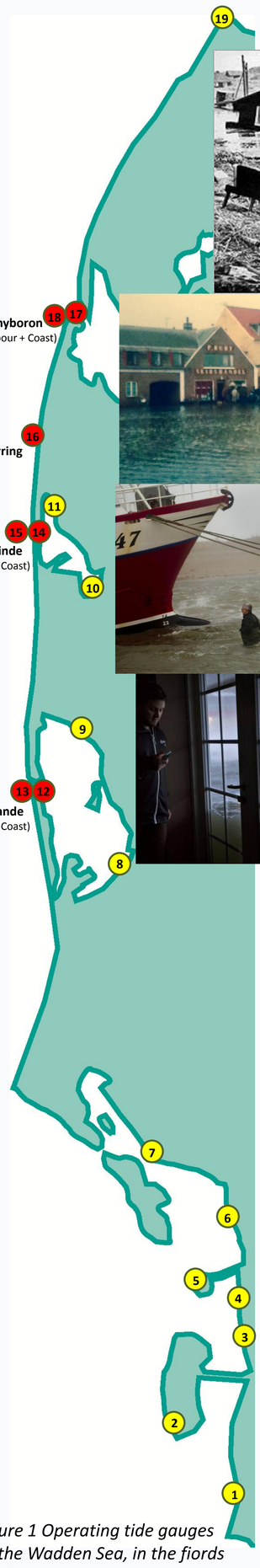
Sand nourishments (2-3 M³/y) counteract erosion on the central North Sea coast of Denmark and dikes and artificial dunes protect the low-lying hinterland from flooding. The fisheries towns of Thyboron, Thorsminde and Hvide Sande are all liable to flooding during storm surges. Tide gauge series from the coast are presented and the town of Thyboron is used as a case where, in addition to SLR and extremes, analyses of land movement and ocean-groundwater interactions are included in an integrated method for assessing future coastal flooding hazards.

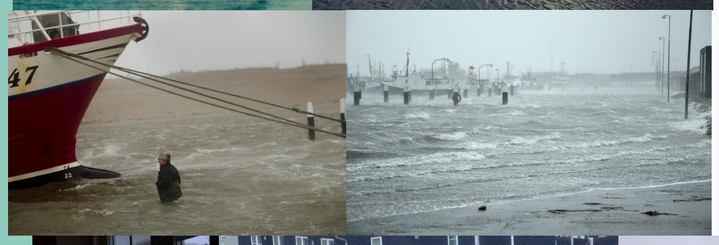
Future coastal flooding hazards in Thyboron

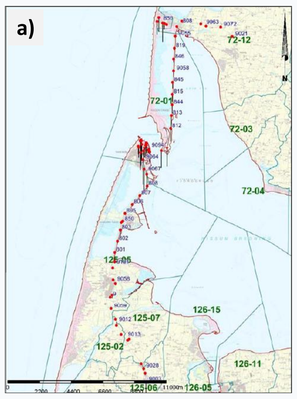
Repeated high-precision levelling campaigns in 2006, 2009, 2012 & (scheduled) 2015 to approximately 40 recently established benchmarks reveal a differentiated net land subsidence of 2-8 mm/y in Thyboron, Figure 4 a-j.

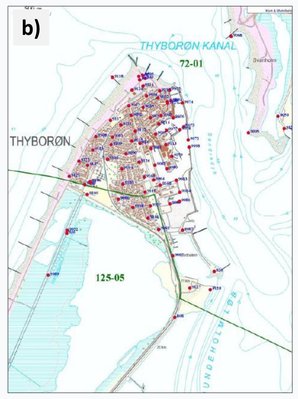
In order to evaluate future flooding hazards in the town, regional projections of climate change (SLR effects on extremes in EVA) are combined with a GIA-model and projections of local subsidence to enhance flood modelling in future scenarios. This acknowledges that floods may be due to ocean extremes, precipitation extremes, groundwater or a combination of these.

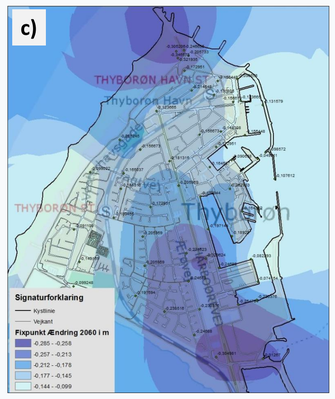
Higher surge levels and land elevation changes (combined in a 'dynamic' DEM) show a more widespread and deeper inundation in the future than caused by climate effects alone. Ongoing research provide details on groundwater fluctuations and on geotechnical soil properties for better predictions of future subsidence and of the joint effects of sea state, precipitation and groundwater on adaptation challenges and options.

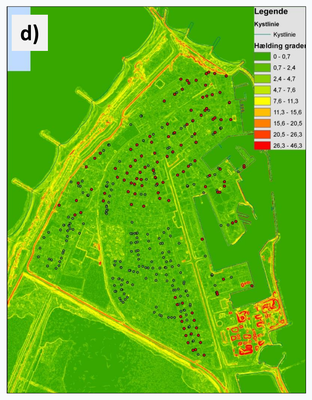


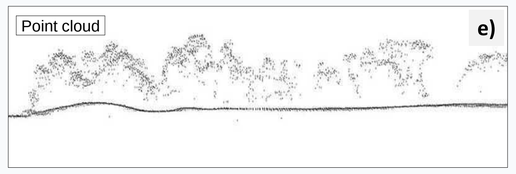


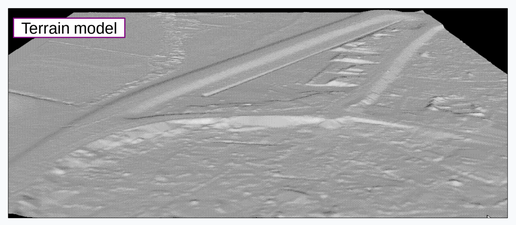


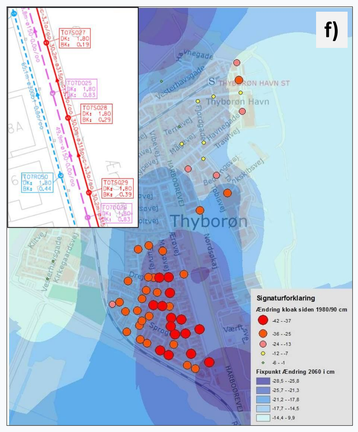


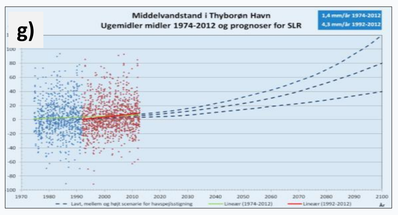


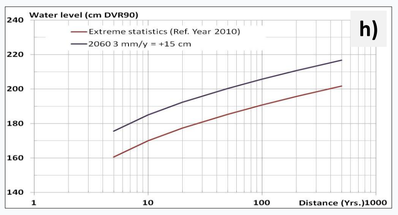


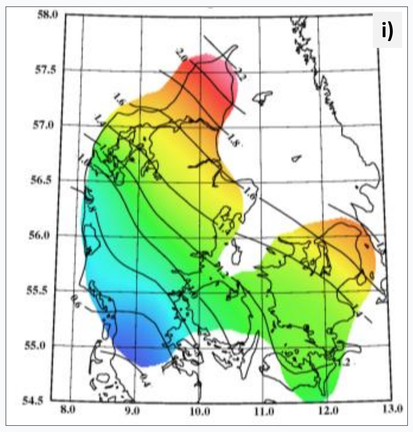












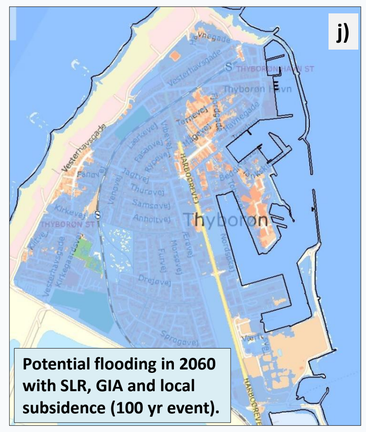


Figure 4 a-j Flooding hazards in Thyboron. Repeated high-precision levelling (a-b) provide a spatially differentiated map of local subsidence (c) which, after corrections of the DEM from levelling of manhole covers (d-e), is included to model the land surface for future scenarios (which may also include sewers, that are found to settle by up to 1 cm/y in the last 30 years (f)). By projecting SLR and its effect on statistical storm surge levels (g-h), and including GIA (i) in the DEM, a more realistic picture of potential future flooding hazards is provided (j).

Tide gauge series

Water levels are monitored by either the Met. Institute, the Coastal Authority (DCA) or local harbour authorities in the Wadden Sea, in the fiords and on the west coast.
Analyses from digital DCA gauges on the coast are presented (red stations in Fig. 1; available time series in Fig. 2), Figure 3 & Table 1. Historic data in analogue forms await digitization.

Data series vary in quality and completeness due to i) the harsh environment causing gaps in data, ii) local effects from wave setup etc. iii) difficulties in (re-)establishing the local zero benchmarks. The latter is due to short- and longer-term land height variations at specific sites, distance to stable height benchmarks, and incomplete metadata from the stations. Through on-going digitization of historic levelling and tide gauge data, a more complete picture is sought for.

Figure 1 Operating tide gauges in the Wadden Sea, in the fiords and on the open coast

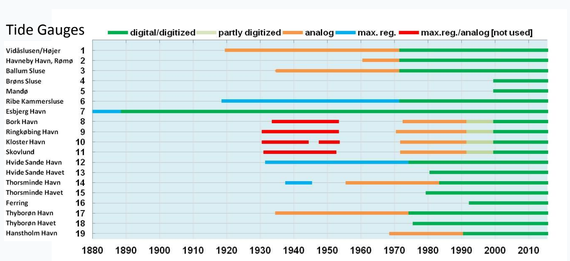


Figure 2 Lengths and data form of tide gauge series on the Danish North Sea coast. Refer to Fig. 1 for positions

Table 1 Calculated changes in mean water levels [mm/y] from linear regressions at tide gauge stations. Except for Hvide Sande (TG's 12-13), rates of change are fairly consistent between tide gauges

Tide gauge	19xx-2012 Yearly	19xx-2012 Monthly	19xx-2012 Weekly	1992-2012 Yearly	1992-2012 Monthly	1992-2012 Weekly
12 Hvide Sande Harbour	0.1	0.8	1.0	**0.7**	**0.7**	**1.2**
13 Hvide Sande Coast	0.3	0.6	0.8	**-4.0**	**-2.9**	**-2.0**
14 Thorsminde Harbour	1.5	2.1	2.4	3.4	3.5	3.9
15 Thorsminde Coast	2.4	2.9	3.5	3.5	2.9	4.0
16 Ferring	-	-	-	4.3	4.1	3.2
17 Thyboron Harbour	0.8	1.4	1.4	3.7	3.7	4.3
18 Thyboron Coast	1.8	0.6	1.4	1.0	2.4	2.7

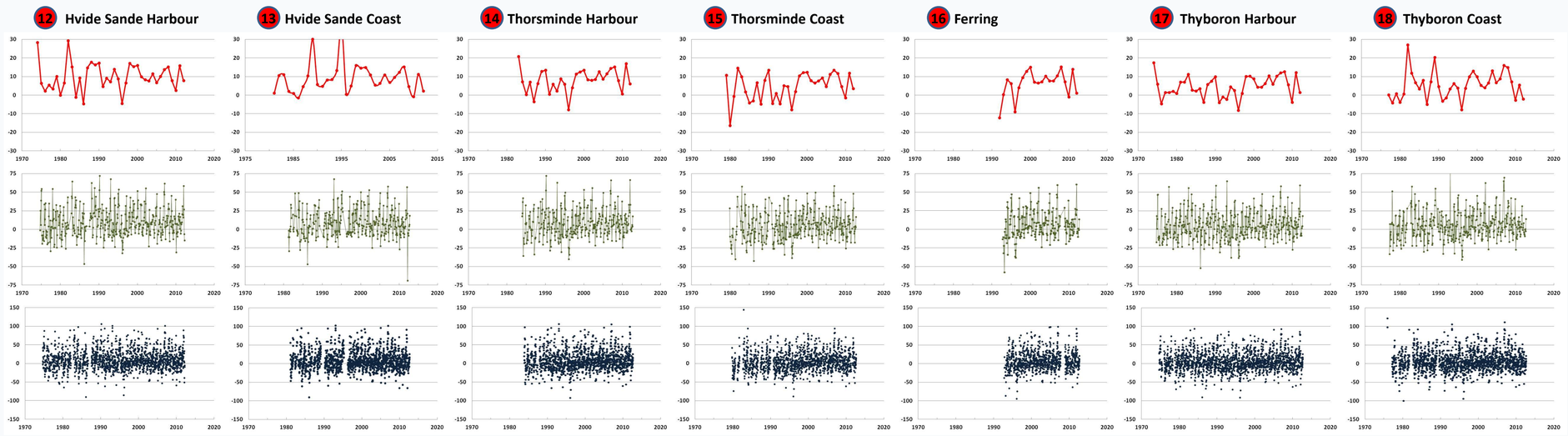


Figure 3 Yearly (top), monthly, and weekly (bottom) mean water levels (MW) at tide gauges (note the different scale [in cm]) in periods of digital recordings. In general, MW show a good correlation between station and with major deviations being due mainly incomplete data sets. In periods with high MW coastal stations tend to be affected by local wave set-up